

I. Analytical Chemistry Division (839)

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A. Division Overview

The Analytical Chemistry Division serves as the Nation's reference laboratory for chemical measurements and standards to enhance U.S. industry's productivity and competitiveness, assure equity in trade, and provide quality assurance for chemical measurements used for assessing and improving public health, safety, and the environment. The Division's activities primarily contribute to the accomplishment of CSTL's measurement science and measurement standards goals through the efforts of its five Groups:

- Spectrochemical Methods,
- Organic Analytical Methods,
- Gas Metrology and Classical Methods,
- Molecular Spectrometry and Microfluidic Methods, and
- Nuclear Analytical Methods.

The skills and knowledge derived from laboratory-based research concerning the phenomena that underpin the measurement of chemical species in a broad spectrum of matrices are applied to the development and critical evaluation of measurement methods of known accuracy, sensitivity, and uncertainty. This expertise in chemical measurement science is deployed in a highly leveraged manner and serves as the foundation for cross-cutting chemical measurement and standards programs in:

- Advanced Materials Characterization
- Analytical Instrument Performance and Calibration
- Environmental Monitoring and Technology
- Forensics
- Healthcare
- Food

Our vision is to maximize this leverage by establishing and maintaining the chemical measurement infrastructure that provides national traceability and is the basis for assessing and improving international comparability, for chemical measurements in these and future high priority program areas. To realize this vision we use and develop infrastructural tools such as:

- Standard Reference Materials
- NIST Traceable Reference Materials (NTRMs)

- Measurement quality assurance programs in critical national areas
- Comparisons of NIST chemical measurement capabilities and standards with other National Metrology Institutes.

Increased requirements for quality systems documentation for trade and effective decision-making regarding the health and safety of the U.S. population have increased the need for demonstrating "traceability-to-NIST" and establishing a more formal means for documenting measurement comparability with standards laboratories of other nations and/or regions. Standard Reference Materials (SRMs) are certified reference materials (CRMs) issued under the National Institute of Standards and Technology trademark. These are well-characterized using state-of-the-art measurement methods and/or technologies for chemical composition and/or physical properties. Traditionally, SRMs have been the primary tools that NIST provides to the user community for achieving chemical measurement quality assurance and traceability to national standards.

Currently, NIST catalogs nearly 1300 different types of SRMs; in 1999 NIST sold over 33,000 SRM units to approximately 6,550 unique customers. Approximately 21,000 of the units sold were



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- Spectrochemical Methods
- Organic Analytical Methods
- Gas Metrology & Classical Methods
- Molecular Spectroscopy & Microfluidic Methods
- Nuclear Methods

from the 850 different types of materials that are certified for chemical composition. Since it has the world's leading, most mature, and most comprehensive reference materials program, most of the world looks to NIST as the de facto source for high quality CRMs to support chemical measurements. NIST has met the reference materials needs of U.S. industry and commerce for nearly 100 years. While our reference materials program has focused primarily on U.S. requirements, it is clear that these materials address international measurement needs as well. As demonstration of quality and "traceability" for chemical measurements have become increasingly global issues, the need for internationally recognized and accepted CRMs has increased correspondingly. Their use is now often mandated in measurement/quality protocols for analytical testing laboratories. Coupled with the fast pace of technological change and greater measurement needs, the demand for additional quantities and additional specific varieties of reference materials has mushroomed. NIST, by itself, does not have the resources to provide SRMs (exact sample types, unique compound combinations, concentrations, etc.) to meet all these needs. Without a significant shift in paradigm, CSTL will not be able to address future needs for reference materials; neither nationally nor internationally.

The NIST Traceable Reference Materials (NTRM) program was created to partially address this problem of increasing needs for reference materials with a well-defined linkage to national standards. An NTRM is a commercially produced reference material with a well-defined traceability linkage to existing NIST standards for chemical measurements. This traceability linkage is established via criteria and protocols defined by NIST and tailored to meet the needs of the metrological community to be served. The NTRM concept was implemented initially in the gas standards area to allow NIST to respond to increasing demands for high quality reference materials needed to implement the "Emissions Trading" provisions of the Clean Air Act of 1990 (while facing the reality of constant human and financial resources at NIST). The program has been highly successful. Since its inception, 11 specialty gas companies have worked with NIST to certify over 7000 NTRM cylinders of gas mixtures that have been used to produce more than 475,000 NIST-traceable gas standards for end-users. According to Stephen Miller, Technical Director, Scott Specialty Gases, "the NTRM program has served as

an excellent vehicle for production of the high quality standards - of known pedigree - required by both industry and the regulatory community in the implementation of Title IV [SO₂ emissions trading] of the 1990 Clean Air Act." The NTRM model for the commercial production of reference materials is being extended to other mature and high volume areas to both more effectively deliver the increasing number of NIST-traceable standards to end users and allow more of our internal resources to be diverted to address new and/or more difficult measurement problems. Immediate plans are to provide NTRMs for optical filter standards, (Spring 2000) elemental solution standards (Summer 2001), and metal alloy standards (Fall 2001). The term NTRM has been trademarked and we are in the process of obtaining a service mark to facilitate its appropriate use by commercial standards producers.

We recognize that the NTRM model is only applicable in selected areas. In the remaining areas, such as complex matrix standards, we have begun leveraging our resources through increased strategic collaborations with other National Metrology Institutes and selected U.S. laboratories. Additional details concerning our collaborative activities with both private sector U.S. laboratories and commercial reference material and proficiency testing service providers as well as other National Metrology Institutes worldwide are provided in Technical Activity Reports 12 – 18.

International agreements and decisions concerning trade and our social well-being are increasingly calling upon mutual recognition of measurements and tests between nations. The absence of such mutual recognition is considered to be a technical barrier to trade, environmental and health-related decision making. In recent years, mutual recognition agreements have been established related to testing and calibration services and in respect of the bodies accrediting such activities. All of these rest upon the assumption of equivalence of national measurement standards and reliability of the link between national measurement standards and the relevant testing services in each country. In October, 1999, the Directors of National Metrology Institutes for the thirty-eight member states of the Meter Convention signed "the mutual recognition arrangement on national measurement standards and calibration and measurement certificates issued by national metrology institutes (MRA). This MRA had been in the works for sometimes and with this

knowledge, we began taking a leading role in the activities of the International Committee of Weights and Measures-Consultative Committee on the Quantity of Material (CCQM) and Interamerican System for Metrology (SIM) – Chemical metrology Working Group. The CCQM activities are focussed on assessing, improving and documenting the equivalence of the chemical measurement capabilities among National Metrology Institutes worldwide. Our activities within SIM are focussed primarily on assessing chemical measurement needs and capabilities among the 34 member economies. We are working with CITAC (Cooperation in International Traceability in Analytical Chemistry) to harmonize the vertical traceability links in the various countries and regions around the world. Additional details concerning these activities can be found in Technical Activity report 18.

In addition to these global and regional activities we are establishing a limited number of strategic bilateral programs. For example, our collaboration with the Netherlands Measurement Institute (NMI) for determining the equivalence of primary gas standards has resulted in a formal “Declaration of Equivalence” that is recognized by the U.S. EPA and European environmental regulatory bodies as documenting the equivalence between seven NIST and NMI primary gas mixtures suites. Details concerning this activity can be found later in the Gas Metrology and Classical Methods section of this overview and in Technical Activity Report 18. We have a formal agreement with NRC-Canada (via the NAFTA Treaty) for cooperation in the development of marine environmental standards and have recently signed a Cooperative Arrangement with NIMC (Japan) for collaborative efforts in the area of pure volatile organic compound standards. Several additional strategic bilateral arrangements with other National Metrology Institutes /Standards laboratories are being discussed.

In addition to our standards activities (SRM, NTRM and strategic international comparisons), providing chemical measurement quality assurance services in support of other Federal and State government agency programs continues to be an important part of our measurement service delivery portfolio. During the past year, we were involved in 13 projects with 6 federal and state government agencies primarily providing them with measurement quality assurance services for environmental and health-related activities. Details concerning many of these

have been provided in past Division overviews. Additional information concerning a relatively new activity--QA Support for Private Sector Provision of Proficiency Testing for EPA/States Drinking and Waste Water programs is mentioned later in two of the Group Sections and Technical Activity Report 17.

Brief overviews of each of the five Technical Groups within the Division follow along with 18 selected Technical Activity Reports. These overviews and reports demonstrate the diversity and breadth of our research program and the services that we provide. They also illustrate the critical synergistic relationships that exist among our research programs and activities in chemical measurement science and the standards and quality assurance services that we provide.

Spectrochemical Methods Group

Research activities in spectrochemical methods are directed toward the development, critical evaluation, and application of techniques for the identification and measurement of inorganic species using x-ray, optical, and mass spectrometries. The focus of this research is measurement accuracy and precision, benchmarking industry's needs for traceability, advanced materials characterization, and commodity value assignment and specification.

The major event of the year was the move to the Advanced Chemical Sciences Laboratory. The move of the Group to the 3rd floor of the ACSL results in a consolidation of offices and laboratories from the 1st, 2nd, and 3rd floors of the old Chemistry Building, and the basement of the Physics Building. This consolidation should allow more cohesive and coordinated work by the group, in addition to providing better functionality—sample handling laboratories and instrument laboratories are now contiguous. The move also forced an assessment of the future directions for the Group and a consolidation of instrumentation. Thermal ionization mass spectrometers (TIMS) were loaned to the Physics Laboratory, several university laboratories, DoE, and the Institute for Reference Materials and Measurement (IRMM) in Belgium. The move punctuated the evolution away from solid source mass spectrometry to inductively coupled plasma mass spectrometry (ICP-MS) for the Group. We now have five ICP-MS; and, only two of the NBS-style TIMS instruments remain.

The X-Ray Fluorescence (XRF) team had a number of accomplishments to its credit this year, in both the measurement and research areas. A collaborative effort with a guest researcher from the Naval Research Laboratory to study and compile XRF fundamental parameters is reported as a technical highlight elsewhere in this volume. Progress continued on a collaborative project with a second guest researcher from Poland studying microbeam XRF. A significant amount of SRM work was also completed. Homogeneity testing was done for about a dozen materials in preparation. The Pb paint films of SRMs 1570 –1576 were re-certified with XRF played a major role in this certification effort. Three cement SRMs were certified—starting a major re-certification program for these important and popular SRM materials. The cement SRM category was the only SRM category that showed increased sales for this year. SRM 1848, Lubricant Additive Package, is a new SRM under development. This SRM is top priority of the lubricants industry and is needed to satisfy their requirements for linking measurements made on finished products to recognized national or international standards. Activities leading to the development of SRM 1848 are described in more detail in Technical Activity Report 11.

The high performance ICP-OES research and measurement effort continues to impact a wide range of activities in the Group. It is an established part of the Spectrometric Solution SRM program, discussed below. In addition, we have continued to promote its broader dissemination. The previous lithium aluminate work was documented for DoE and a publication is in review. The method is now being successfully applied by DoE to qualify material to the narrow specifications allowed for producing tritium safely in a civilian reactor. The ability to achieve high performance using two other manufacturers' ICP-OES instruments was also demonstrated this year. One of these instruments was in the laboratory of a provider of secondary standards. The experiments were done as part of a beta test of our proposed NTRM program for solution standards. The results of this collaborative work was presented at two conferences. In the international arena, we have collaborated with EMPA in Switzerland to characterize a series of elemental solutions that will be distributed as part of a CCQM key comparison (CCQM K-8). The relative standard errors of replication for the four elemental solutions prepared (Fe, Cu, Al, and Mg) were all better than 0.01 %.

The improved ICP-OES method has been presented in the context of “replacing classical analysis.” It matches the precision and approaches the understanding of sources of error of classical analysis, especially for cases where the sample can be reduced to a simple dilute solution, as is done for the spectrometric solution SRMs. We have extended the concept this year by assaying the major elements in a more complicated sample, SRMs 1775/2175, a high temperature alloy with Ni, Mo, Cr, and Co as its major constituents. A multielement experimental plan and calibration strategy was applied to determine these elements. The relative standard uncertainties for replication were 0.02 %. Because of the rigor and labor intensity required, classical analysis is an expensive and disappearing capability in analytical chemistry. The results of this work were presented to a group of analysts in the metals industry in July. These analysts echoed a common theme whenever this work is presented—“how do I procure this capability for my laboratory?” We will continue to promote the process of technology transfer both by working with manufacturers and by demonstrating and publicizing the possibilities.

One of the research areas generally studied by the Group was the improvement of instrumental performance in the presence of drift as described in one of the technical highlights. One application was in glow discharge optical emission spectrometry (GD-OES). This work identified a source of drift in GD-OES and showed how it could be accounted for by applying an appropriate calibration strategy. Subsequently, the manufacturer has made hardware modifications that should alleviate the source of the drift—an example of how our research can have immediate impact. A second research activity in GD-OES was the study of the analytical benefits of alternative and mixed gases. This work was started through a collaboration with Clemson University and funding by NSF. Various figures of merit were assessed for glow discharges using pure Ne, Ar/Ne and Ar/He mixtures, and compared to Ar. Initial results indicate that there are only minor benefits for the extra effort expended, and this conclusion runs counter to published observations in this field. Finally, a major research effort was undertaken in the analysis of SRM 1775/2175, a high temperature alloy, this year, as part of the Division's exploration of new methods for certification of metals. The comparative results versus XRF and other methods, e.g. HP-ICP-OES described above, were instructive

and showed that there is still a great deal to be learned about the technique.

Inductively-coupled plasma mass spectrometry is now the measurement workhorse for the group, continuing the trend begun in 1985 when the first instrument was procured. This year, we procured the fifth instrument for the group and installed it in the Division's laboratory in Charleston, South Carolina. The first inorganic analytical chemist to be stationed in Charleston was identified and he spent the year in Gaithersburg becoming familiar with the methods and procedures that used by the group. He moved to Charleston in August, and has overseen the completion of the inorganic facility, anchored by the ICP-MS, but also including a clean sample preparation area to allow trace element determinations. While at NIST he participated in the certification of Hg in several materials, and performed other Isotope Dilution-ICP-MS measurements. He also collaborated in a research project that investigated the coupling of a commercial cold vapor atomic absorption spectroscopy (CV-AAS) instrument with ICP-MS for mercury measurement. This method was used in the certification program for SRM 1641d Trace Mercury in Water and SRM 966 Heavy Metals in Blood. The key innovation was the ability to quantify the results using two distinct methods, including isotope dilution mass spectrometry.

Thermal ionization mass spectrometry is still the method of choice for high precision isotope ratio measurements and the Group has developed an isotope dilution mass spectrometry method for chlorine that addresses the need to quantify this gaseous non-metal in complex matrices. This work builds on a previously developed ID-TIMS method for chlorine in blood/serum that is not generally applicable to other materials; a new procedure for high precision chlorine isotope ratio measurement; and, a new chlorine extraction procedure. This work is an extension of a postdoctoral research project to measure and understand natural variability of chlorine isotopic abundances in geological materials. The determination of concentration by isotope dilution is a logical adjunct. The pyrohydrolysis technique for extraction of the chlorine is also being investigated for extraction of mercury, and direct coupling to an ICP-MS. European and US environmental agencies recently have expressed concern about chlorine and mercury emissions in the burning of fossil fuels and proposed rules to monitor these

emissions. These rules will require standards to benchmark measurement of these elements in the fossil fuels—critical measurements needed to understand and assess the magnitude of the problem. The certification of both elements in existing coal SRMs will serve this benchmarking need.

The Group took over the production and certification of the Single Element Spectrometric Solution SRM program at the beginning of the year, which included transfer of two scientists from the Gas Metrology and Classical Methods Group. The process by which these SRMs are certified was completely reengineered. A system for the production of weighed aliquots of primary standard solutions was implemented. These primary materials will serve as the basis for a new class of elemental solution SRMs designed for use as traceability transfer standards, and will be used in the development of an elemental solution NTRM program, described further in the NTRM Technical Activity Report 16.

Organic Analytical Methods

Research activities in organic analytical methods are directed toward the development, critical evaluation, and application of methods for the identification and measurement of organic and organometal species using organic mass spectrometry and analytical separations techniques. These separation techniques include gas chromatography (GC), liquid chromatography (LC), supercritical fluid chromatography (SFC) and extraction (SFE), capillary electrophoresis (CE), and capillary electrochromatography (CEC).

Recent research activities in organic mass spectrometry have focused on the development of techniques for characterization and quantitative determination of proteins in biological matrices. We are developing a number of primary and reference methods for important biomarkers such as troponin-I (a new marker of myocardial infarction), glycated hemoglobin (an important new marker for diabetes), and serum thyroxine (an important marker for thyroid function). Techniques have been developed for the chemical characterization of purified troponin-I preparations, thus providing a means for comparing the molecular structure with results from field studies involving immunoassays. Two new LC/MS instruments are providing new capabilities for the determination of analytes of health, nutritional, forensic, and environmental importance, as well as for structural studies of natural products.

Our new high-resolution mass spectrometer is being used in the development of methods for complex environmental contaminant mixtures such as dioxins, furans, and toxaphene as a prelude to future certification measurements of these substances in natural matrix SRMs. Ion-trap mass spectrometry is being combined with chemical ionization (CI) to improve the measurement of polyunsaturated fatty acids. Fatty acids such as these are found in fish oils and are believed to provide health benefits; however, their determination by mass spectrometry is hindered by their extensive fragmentation under electron ionization conditions, but with CI and acetonitrile as the source of reagent ions, it is possible to obtain strong signals for characteristic ions from these compounds. Mass calibration of mass spectrometers used for high molecular weight species is difficult and few appropriate materials are available. Research is underway to develop a set of proteins produced by bacteria grown in a media depleted in ^{13}C and ^{18}O . Such proteins will have much simpler isotope clusters which will be useful for mass calibration in matrix assisted laser desorption ionization (MALDI) and electrospray mass spectrometry of biomolecules.

Research activities in separation science continue focus on investigations of the physical and chemical processes that influence retention in LC, GC, SFC, CE, and CEC. Results from these fundamental studies are used to design stationary phases tailored to solve specific separation and analysis problems, and to assist in method development and optimization. Recently we have explored a novel approach to the synthesis of LC stationary phases based on polymer immobilization. Polyethylene acrylic acid copolymers were immobilized on silica as an alternative to conventional silane surface modification chemistry. The resulting columns were evaluated for the LC separation of carotenoid isomers, and preliminary results indicate exceptional selectivity for this class of compounds. Further optimization of this promising stationary phase should result in improved measurement capability for carotenoids and related nutrients in food and tissue samples. Research in chiral separations is continuing in several areas using LC, CE, and GC. The determination of chiral drug species in hair samples using LC may permit environmental exposure to be distinguished from illicit use. Studies have been carried out with a model chiral compound (metoprolol) to evaluate the potential of this approach, for eventual application to amphetamine and methamphetamine. In other

studies, functionalized cyclodextrins have been evaluated as chiral selectors in CE. The use of dimethyl-, hydroxypropyl-, and sulfated- forms of β -cyclodextrin improve aqueous solubility and alter the chiral recognition properties of this compound. Finally, chiral GC methods have been developed for the determination of DDT and DDE in environmental samples where enantiomeric resolution required coupling of chiral and achiral columns.

Insights gained from our research in separation mechanisms have provided us the knowledge to develop two new LC column performance test mixture SRMs. SRM 870, Column Performance Test Mixture, will be used to characterize LC column properties such as silica silanol activity, trace metal activity, and separation efficiency. SRM 877, Column Selectivity Test Mixture for Chiral Separations, will be useful in predicting the performance of columns for resolving enantiomers.

Our research in organometal speciation has continued with improvements in the GC-atomic emission-based method for methylmercury and alkyl tin species. The new approach involves derivatization and a solid phase micro-extraction (SPME) step to concentrate the analytes and has been used to provide data for certification of methylmercury in SRM 2977 Mussel Tissue and SRM 1566b Oyster Tissue. During the coming year the method for methylmercury will be applied to additional SRMs including SRM 1946, Lake Superior Fish Tissue, and SRM 966, Toxic Metals in Blood. This same general approach will also be used to measure tributyltin in several of the marine matrix SRMs. Other research has involved development of multidimensional chromatographic approaches for quantification of non-ortho polychlorinated biphenyl congeners (considered to be the most toxic congeners) in some of our existing cod liver oil, sediment, and whale blubber SRMs, and nitro-substituted polycyclic aromatic hydrocarbons in diesel-related SRMs.

We have developed a method using pressurized fluid extraction and GC/MS or GC with electron capture detection to assess the micro-homogeneity of organic contaminants in natural environmental matrices. The method has been applied to air particulate, diesel particulate, frozen mussel tissue, and sediment SRMs. For the air particulate SRM, the amount of material that yields a 1% sampling error (due to heterogeneity) varies with analyte from approximately 50 mg to 450 mg, whereas the

amount of diesel particulate material that yields a 1% sampling error varies only between 40 mg and 80 mg. Certificates of Analysis for these SRMs will be updated with this new information.

Even with the downtime experienced by the move to our new quarters, a number of high priority natural matrix SRMs were completed this past year. These were:

- **SRM 1546 Meat Homogenate**, which was identified by the USDA, FDA, and the food industry as a high priority need was completed with certified values for cholesterol, six fatty acids, calcium, sodium, iron, and total nitrogen, and reference values for proximates, calories, a number of other fatty acids, and some additional nutrients.
- **SRM 1944, New York/New Jersey Waterway Sediment**, with over certified values for 70 species including several polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), chlorinated pesticides, and trace elements. Reference Values were provided for 80 additional species including selected polychlorinated dibenzo-p-dioxins(PCDDs) and dibenzofurans(PCDFs)
- **SRM 1649a, Urban Air Particulate Matter**, has certified/reference values for over 100 PAHs, PCBs, chlorinated pesticides, and PCDDs/PCDFs, as well as values for total organic carbon, percent extractable material, carbon composition, particle-size information, and trace elements.
- **SRM 1589a, PCBs in Serum**, has PCBs at naturally occurring levels in contrast to its predecessor where high levels of Aroclor mixtures were spiked into serum. This replacement material has been analyzed at NIST and the Center for Disease Control to provide certified and reference values for PCBs, chlorinated pesticides, and PCDDs/PCDFs.

A number of new SRMs are nearing completion. Details concerning these activities can be found Technical Activity Reports 12-14.

The research and standards development activities within this Group have resulted in over 50 manuscripts either submitted, in press, or published in refereed journals during the past year. Nine papers were published or accepted by the journal Analyti-

cal Chemistry, two of which were featured in the "A" pages, which are authoritative, high visibility reviews of specific topics written for a broad audience.

Gas Metrology and Classical Methods

Research activities within the Gas Metrology and Classical Methods Group are focused on gas metrology, classical wet chemical methods (gravimetry, titrimetry), coulometry, ion chromatography, and maintenance of the theoretical infrastructure for pH and conductivity measurements.

This year the move into the new building interrupted our programs for approximately three months. Despite this, we have had a very productive year due to the dedication and hard work of our staff. As seen below, this interruption had little effect on the number of SRMs, NTRMs, and Data Products delivered by this group. Also despite the move, the group was able to provide two courses, one of Classical Methods and the other on Gas Metrology, for representatives from other national standards laboratories within the Americas. These courses were very well received and are the only ones scheduled for repeat during the coming year.

During FY99 the following SRMs were completed; 15 gas cylinder, 3 anion solution, 12 conductivity, 2 ion activity, 6 Volatile Organic Compound solutions and a zeolite material. A total of 170 gas cylinder SRMs were recertified for 15 companies. While these certified reference materials are critically needed, their continuous production consumes considerable fiscal and human resources and limits our ability to address new standards needs. The gas NIST Traceable Reference Materials (NTRM) Program was created to address this concern. In FY99, we worked with 7 specialty gas vendors to certify 66 NTRM batches. The over 1000 individual gas cylinders in these certified batches will be used to produce approximately 100,000 NIST-traceable gas standards for end-users. Over the next year we will be defining a new approach for gas NTRM certification that will allow Specialty Gas Companies to expand their production while still maintaining the strong linkage to National Standards maintained at NIST.

Over the past year we have restocked all conductivity solution SRMs, thus recovering from a shutdown of this program two years ago when the person responsible for this program left NIST. In the

past, leakage and transpiration limited our certification period to less than 1 year. Based on a pilot study involving three of our prime customers, we determined that switching to serum bottles provides stability for more than two years. We are planning on moving all conductivity solution SRMs into this bottling scheme in the next year. In addition we have revived an intercomparison with Hungary and Denmark on conductivity, and have championed a paper on molality-based electrolytic conductivity through IUPAC.

The area of pH standards continues to receive much international attention. Our active participation in IUPAC Commission V.5 resulted in acceptance of the Bates-Guggenheim convention, thus assuring continued traceability of pH to sound thermodynamic principals. We were also instrumental in defining the recommended values of uncertainty for the draft document on pH standards. This effort caps a three-year activity to defend the present pH scale from a simplified, yet non-traceable, scale championed by a few participants in V.5. Conversion to a new scale would have needlessly impacted U.S. industry financially. As a result of our active leadership in V.5, Ken Pratt has been nominated for Titular Membership in IUPAC. NIST also participated in both CCQM and European Union intercomparisons on pH. We have also organized an intercomparison to assess pH measurement capabilities within SIM.

Other activities in the classical methods program include research to improve the quality of our anion solution SRMs and certification of Si in a zeolite material using gravimetry coupled with XRF to account for additive interferences. This approach allowed the certification of Si in the Zeolite SRM with a relative uncertainty of 0.1 %.

In collaboration with EPA and the remote sensing community, we have developed a quantitative database of infrared spectra, which is required for establishing FTIR-based technology as a reliable tool for real-time monitoring for airborne chemical contaminants along plant boundaries and within plant facilities. Because the spectra are being prepared using NIST primary gas standards, well-defined traceability to NIST can be established for any subsequent field measurements. These spectra will be required to be used in the new update of EPA method TO-16. More information concerning this activity, and the most recent release of a CD-ROM

containing spectra for 30 high priority species, can be found in Technical Activity Report 7. Future efforts will address continued data acquisition for compounds listed in the 1990 Clean Air Act amendment that are measurable with FTIR as well as additional compounds that contribute to global warming and ozone depletion.

In June 1999, the Ozone standards activities were transferred from the Surface and Microanalysis Division and integrated into the Gas Metrology program. NIST ozone standards effort supports a network of 22 Reference Photometers that provide NIST traceability for ozone measurements for the EPA and many International agencies. These Standard Reference Photometers (SRP) were designed and built at NIST and certified against the U.S. National Reference Photometer maintained at NIST. Currently we are upgrading these field photometers with new hardware and software

To assist the U.S. automobile industry, we are developing and evaluating new analytical measurement tools and providing standards needed to address compliance issues associated with the Clean Air Act of 1990. We are developing an infrared-based sensing device and are working with the NIST Physics Laboratory to evaluate a new Fourier Transform microwave device for real-time detection of oxygenated hydrocarbons in automobile exhaust. A series of new cylinder-based gas SRMs for low emission vehicles also are being produced to support U.S. automobile manufacturers in the development of the next generation of "clean" cars. For example, we are currently developing low concentration ($<5 \mu\text{mol/mol}$) nitric oxide gas standards to meet future regulations on automobile emissions. This effort will take approximately one additional year to complete and will result in new gas cylinder SRMs, since these standards are not suitable for the NTRM program. We will be collaborating with the Netherlands Measurement Institute and the National Physical Laboratory of the UK in this effort.

Molecular Spectrometry and Microfluidic Methods Group

The Molecular Spectrometry and Microfluidic Methods Group conducts research on or has responsibility for:

- the metrology of molecular spectrometry and develops standards for calibration, validation, and performance of instruments for measuring molecular spectra;
- conducts research on microfluidic devices, methods, and applications for chemical analysis including studies of materials and material properties affecting the flow of liquids in microchannels and the use of microchannel and other electrophoretic methods for forensic and toxicological applications and standards;
- the development and certification of optical transmittance and wavelength standards in the ultraviolet, visible, and near-infrared spectral regions; and
- works with users and manufacturers of analytical instruments to assess and measure the performance of analytical methods and to determine and address existing and future needs for analytical instrument standards ranging from device calibration and instrument performance through specifications for remote device control and data interchange.

In FY99, 102 solid absorbance filter SRMs were certified, and 189 optical filter sets were recertified. In addition, 250 units of SRM 2034 (holmium oxide uv-vis wavelength standard) and 98 units of SRM 2035 (NIR transmission wavelength standard) were certified. Measurements were completed on a 100 unit batch of SRM 2035a and research was conducted on a reflectance version of this material that will be designated SRM 2036. Development was begun on SRM 2037, a standard for calibrating the amounts of the red dye used to mark off-road diesel fuels for tax purposes, by acquiring a bulk material that contains the required Solvent Red 26 dye in ~85% purity. After further purification, the material will be certified for molar absorbance at two wavelengths in representative solvents. The new high accuracy reference uv-vis spectrophotometer was moved and installed in the ACSL. The software to control the instrument components was completed and validation and verification of the spectrophotometer has begun. A intercomparison of uv-vis absorbance filters (both gray glass on metal-on-fused-silica filters) was conducted between NPL,

NIST-PL (vis only), and NIST-CSTL. All of the measurement results were within the uncertainty limits over the ranges that we support.

Three glasses (a chromium glass for 785 nm, a uranium glass for 532 nm, and an europium glass for 1064 nm) have been identified as promising candidate source intensity correction standards for Raman systems with 785 nm, 532 nm, or 1064 nm lasers. These glasses provide fluorescence spectra that, when calibrated against a standard white light integrating sphere source (calibrated by the NIST Optical Technology Division), can be used to correct Raman spectra for laser color and intensity variations. This in turn will allow Raman spectra to be made essentially instrument independent and will facilitate the development of Raman spectra libraries. At present, the chromium glass has been characterized sufficiently well to permit its being sent out to ASTM Raman subcommittee members for a round robin evaluation.

A program to develop standards for luminescence spectrometry was initiated with a Workshop at NIST attended by over 40 scientists including representatives from five National Metrology Institutes. Over 60 candidate substrates, glasses and fluor-impregnated PTFE materials, have been examined for their potential as fluorescence standards. In collaboration with the Biotechnology Division, we have begun developing a fluorescein solution SRM that will be certified for purity and for concentration. The material is to be used to peg the MESF (moles of equivalent soluble fluorophore) scale used in flow cytometry.

The optical filters NTRM program was announced publicly at a Pittcon Workshop in Orlando, FL and in two articles in Spectroscopy magazine. A NIST Special Publication (SP 260-140) and a supplement to NVLAP Handbook 150 that define this NTRM program were written, reviewed, and are now being sent to interested parties with an invitation to enroll in the initial class of NTRM producers. At least four companies are expected to participate and begin selling NTRM gray glass optical filters early in 2000.

We have initiated a project through the Office of Law Enforcement Standards at NIST to advance and support the concept of quantitative measurements for forensic analysis. Specifically, we have been developing a quantitative extraction and

analysis method for the recovery of gunpowder additives based on ultrasonic liquid extraction and micellar capillary electrophoresis. In FY99, the technique was used to quantitatively compare the chemical composition of gunpowder residues to unfired gunpowder for identification. We are embarking on an effort to develop a standard reference material "Additives in Smokeless Gunpowder" that will help law enforcement agencies such as ATF and FBI to validate measurement methods for the composition of gunpowder and residue samples that are submitted for forensic identification.

We have partnered with the Electronics and Electrical Engineering Laboratory on a project supported through the NIST Advanced Technology Program to design and build silicon chips with microheating elements combined with channel interconnects in silicon, to devise methods for linking silicon chips to plastic microfluid devices, and to test heater operation in fluids for coupling to chemical reactions. We developed some new concepts to fabricate devices for this project and have leveraged some of the knowledge acquired in the course of this work to design new devices for a "Microscale Analytical Laboratory" project discussed in Technical Activity Report 6.

In conjunction with the Biotechnology Division, we provided the data analysis, analysis justification, value assignment, and certificate modification required for the recertification of SRM 2390, RFLP Profiling Standard. All forensic laboratories performing RFLP measurements are now required to analyze this SRM at least once a year to be eligible to receive Federal funding. Working with Guest Researchers from the Fochhochschule in Wiesbaden, Germany, we have extended our previous efforts to develop a device capability dataset (DCD) concept to the system level, defined and documented the system capability dataset (SCD), implemented a DCD for the HP 8453 spectrophotometer, and detailed the handling of result data by the SCD. Oliver Borchert received a second prize for his poster on dealing with result data using an SCD at the LabAutomation 99 conference in San Diego.

Nuclear Analytical Methods

Research activities in this group are focused on the science that supports the identification and quantitation of chemical species by nuclear analytical techniques. Current laboratory research activities in-

volve the full suite of nuclear analytical techniques including instrumental and radiochemical neutron activation analysis (NAA), prompt gamma activation analysis (PGAA), and neutron depth profiling (NDP), as well as applications of neutron focusing technology for analytical applications. The measurement capabilities that reside within this group provide an excellent complement to those in the Spectrochemical Methods Group in that they depend upon characteristics of the nucleus of the element rather than the electron shells, and therefore are insensitive to chemical state. In addition, the nuclear analytical are generally nondestructive and thus do not require sample dissolution.

NAA is a powerful reference technique that has been used at NIST for many years. New developments continue to provide improvements in detection sensitivities, elemental specificity, precision, and overall accuracy that allow it to address new measurement needs. We have recently been developing Instrumental NAA procedures and applying them to study the homogeneity of SRMs at small sample sizes. Many analytical techniques used in industry and academia rely on the analysis of very small samples (i.e., 1 mg), typically in the solid (undissolved) form. Unfortunately most SRMs are certified with minimum sample sizes of 100-500 mg, and are therefore unsuitable for use as control materials for these techniques unless additional information is made available. Taking advantage of the sensitivity and nondestructive properties of INAA, the use of this technique for homogeneity studies of small samples has been evaluated and implemented for the determination of sampling characteristics for a number of environmental SRMs. The minimal analytical uncertainty associated with the INAA measurements allows extraction of the variability due to material inhomogeneity from the observed total variability in a set of measurements. We have investigated three sediment materials that have shown the potential for a high degree of homogeneity at very small sample sizes for possible use as a future SRM aimed at solid-sampling analytical techniques. From the candidate materials a portion of the Baltimore Harbor Sediment, currently under certification for organic constituents (SRM 1941b) was selected for further processing as SRM for trace elements as well as for microanalytical techniques. Evaluation of the Ingamells model describing homogeneity has been initiated with the Statistical Engineering Division.

Instrumental neutron activation analysis has been used as a primary method for certification of the arsenic implanted dose in SRM 2134, Arsenic Implant in Silicon. This material has been a high-priority need of the semiconductor industry for a number of years. It was produced and characterized in collaboration with the Surface and Microanalysis Science Division and is intended for use as a calibrant for secondary ion mass spectrometry. The INAA results used for certification contains the first complete, quantitative evaluation of all sources of uncertainty in an INAA measurement. The expanded relative uncertainty for the mean value of this SRM was 0.38 % and approximates the 95 % level of confidence.

Significant advances have been made this year in the use of state-of-the-art signal processing techniques in our gamma-ray spectrometry systems that are used for INAA. Losses through pulse processing dead time and pile-up are best assayed with an external pulse technique. In this work, the virtual pulse generator technique as implemented commercially with the Westphal loss free counting module has been set up and tested with four high resolution gamma-ray spectrometers. Dual source calibration and decaying source techniques were used in the evaluation of the accuracy of the correction technique. Results demonstrated the reliability of the LFC with a standardized conventional pulse processing system. The accurate correction during high rate counting, including during rapid decay of short-lived activities, has become the basis for highly precise determinations in reference materials studies.

Pioneering research is conducted by this Group on the use of cold neutron beams as analytical probes for both PGAA and NDP. PGAA measures the total amount of an analyte present throughout a sample by the analysis of the prompt gamma-rays emitted immediately following neutron capture. NDP on the other hand, determines the concentrations of several important elements (isotopes) as a function of depth within the first few micrometers of the surface by energy analysis of the prompt charged particles emitted during neutron bombardment. Both of these techniques continue to make important contributions in the characterization of advanced materials, particularly with the enhanced sensitivities now available using cold neutrons from the NIST Reactor.

A method has been developed and an apparatus built to produce titanium (and other metal) SRMs of known hydrogen concentration on the few-kilogram scale. The method is based on the controlled reaction of hydrogen with titanium in a closed system. Homogeneity is checked by neutron incoherent scattering, and concentration is verified by cold-neutron prompt-gamma activation analysis and gravimetry. The first SRM material has been prepared near the critical level of 100 mg/kg. In addition, new materials will be prepared at two bracketing levels. The apparatus has also been used to prepare standards for neutron-tomographic nondestructive analysis of turbine blades at McClellan Air Force Base.

We are currently developing and critically evaluating a nondestructive technique to quantitatively determine hydrogen based upon neutron scattering. This will serve as a complement to PGAA measurements for this element. The incoherent scattering cross section of neutrons by the H nucleus is much greater than that of any other nuclei; and the H scattering cross section is much greater than the absorption cross section. These two properties accentuate the potential of neutron incoherent scattering (NIS) for rapid H determination. In addition, NIS has very-limited overlap of error sources with PGAA, and agreement of results between the two techniques provides a high degree of confidence.

We have begun measurements of nitrogen in chemical vapor deposited diamond films by NDP. Several problems have been identified including the elevated background from gamma-ray induced electrons. While the initial results are encouraging, more effort needs to be made to improve the signal-to-background levels. These improvements will be useful in future measurements of SiON, which is of importance to the next generation of semiconductors. We are continuing our measurements of lithium migration in thin films, as applied both to electrochromic multilayers and to lithium batteries. NDP is well suited to these studies as lithium mobility can be observed in "real" time.

The cold-neutron PGAA and NDP spectrometers, which are available to outside researchers as part of the NIST Center for Neutron Research "national users' facility", continue to provide high-quality measurements for outside scientists. Current experiments of interest at the NDP instrument include the measurement of shallow-doped boron content in

silicon in conjunction with Advanced Micro Devices, calibration of boron in-house standards for Lucent Technologies, and the characterization of boron and nitrogen thin films in a wide variety of materials for high tech applications.

Non-destructive, matrix-independent measurements of hydrogen by the cold neutron PGAA technique have become particularly valuable in view of the difficulties of accurate determination of this element by other techniques. Many of the current PGAA experiments involve measuring hydrogen in a wide variety of materials for different applications. These include: metal embrittlement studies, studies of materials for new types of lithium batteries and fuel cells, and the determination of H concentrations for materials prior to neutron scattering measurements. PGAA has also been used along with neutron incoherent scattering (NIS) to map the hydrogen content of wet concrete samples as a function of position in an effort to create a moisture profile of the material and hence monitor the uniformity of drying. Other measurements made at the PGAA facility this year include: the determination of H, S, Ca, and K in Nafions, derivatives of Teflon which have potential use as membranes in electrochemical separations and in fuel cells; the characterization of antiferromagnetic materials which are of interest to the superconductor industry; and the analysis of a Martian meteorite, to serve as a prototype spectrum in the design of a PGAA instrument for analysis of the Martian surface. PGAA has also been used with focused neutrons has been used in the determination of chromium in a chromite layer deposited on steel casings which are used in Kraft recovery boilers by the pulp and paper industries for process chemical recovery.

Efforts continue within the group to develop the techniques and methodology of focusing cold neutron beams for analytical applications of PGAA and NDP. A monolithic lens consisting of a fused tapered bundle of polycapillaries that provides a smaller focus of about 0.15 mm (FWHM at the focal spot) has been installed in the NDP chamber. The chamber has also been modified to accept a separate lid through which the lens can be mounted for remote-controlled alignment. A new alignment system containing a CID camera with vacuum capability has also been installed. It provides a spatial resolution of 12 μm (pixel size) and an 8 bit dynamic range for the neutron intensity, and provides the possibility for charged particle imaging. To-

gether with the new vacuum-compatible motion stages, the alignment system permits measurements without breaking the vacuum. Furthermore, the lens can be retracted out of the beam for measurements on the same sample with normal NDP geometry. The new lens and focusing system now gives us the capability of measuring samples as small as ~ 0.1 mm in diameter or, together with our current scanning system, of measuring concentrations in three dimensions with much improved spatial resolution. Previously, our three dimensional profiles were performed with beam spot sizes of 1 cm.

The Group organized and conducted the highly successful "Tenth International Conference on Modern Trends in Activation Analysis" in April 1999. This quadrennial meeting brings together the worldwide community to assess nuclear analytical techniques and their applications, with emphasis on innovative recent developments. This session was attended by 204 scientists from 37 countries.

Future Directions

All Division research and service projects are reviewed on an annual basis for quality, progress, and match to mission and customer needs. The chemical measurement science and cross-cutting program areas on which the Division's research and measurement service activities are focused will not change very much in the coming year. We will continue to redirect some of our efforts to expand our programs in analytical instrument calibration transfer and performance and clinical biomarker standards. As mentioned earlier, we are beginning a major new effort in microanalytical device measurement technology.

We will continue to focus more of the Division's resources on chemical measurement science and the development SRMs with improved accuracy and uncertainty levels, and expand our collaborations with commercial reference material suppliers for providing NIST- traceable secondary standards to meet day-to-day end- user needs. The Division's budget for Standard Reference Materials activities has been $\sim \$3\text{M}$ for each of the past several years. During this period, the majority of our efforts have focused on renewals urgently requested by customers and few resources have remained for development of standards to address new measurement problems/needs. The gas NTRM program described previously has provided some relief and over the

past three years, we have been able to initiate efforts for development of a number of new, high priority SRMs including the following that will be completed during the coming year:

- **Aircraft Alloys** (P and S to be certified; materials failure related to P and S concentration)
- **Drinking/Wastewater Standards** (to provide accuracy benchmark and measurement traceability for proficiency testing of >5000 environmental laboratories conducted by commercial providers)
- **Fish Fillet** (PCBs, pesticides, methylmercury and food proximates to be certified)
- **Isotopically-depleted Protein Mass Standards** (with 831; for use in calibrating mass scale in 1,500-50,000 dalton range)
- **Lubricating Oil Additives** (to certify 12 elements for providing QA and required measurement traceability for \$5B/yr Lubricants Industry)
- **Moisture in Crude Oil** (moisture levels, like sulfur, greatly influence price of crude oils)
- **Transmission NIR Wavelength Standard** (For precise calibration of spectral region of increasing industrial interest)
- **Zeolite Catalysts** (Na, Si, Al, Fe, and trace metals to be certified)

In addition, work is continuing on multiyear projects with SRMs scheduled for completion in FY01 for the following:

- **Cardiac Troponin I** (new definitive biomarker of heart attack not being effectively utilized due to measurement problems)
- **NIR Transflectance** (wavelength standards suitable in form for calibration of single- and double-pass transmission in both wavenumber and wavelength)
- **Liquid Baking Chocolate** (to complement suite of SRMs developed in response to new nutritional labeling laws)
- **Frozen Spinach** (to complement suite of SRMs developed in response to new nutritional labeling laws)
- **Antibiotics in Milk** (for QA of HPLC tests used to accept/reject >50,000 lots of milk per year)

Work will begin during the coming year on several new SRMs for new clinical diagnostic markers.:

- **Folates** (important antioxidants; neural tube defects and blood homocysteine levels)
- **Homocysteine** (marker for heart attack risk)
- **Glycated Hemoglobin** (diabetes diagnostic marker)
- **Ionized Calcium** (important marker for diagnosis of various disease states such as skeletal resorption and stone formation in the urinary tract)
- **Thyroid Stimulating Hormone** (marker of thyroid function)
- **Speciated Iron** (marker for anemia and hemochromatosis; to address clinical need to measure iron associated with various iron-containing proteins)
- **Bilirubin** (marker for liver function)
- **Total and Speciated Selenium** (to support clinical monitoring in the relatively narrow range of beneficial effect)

The major driver for this escalation of our clinical standards program is an In-Vitro Diagnostic Devices Directive (IVDD) scheduled for initial implementation in December 2003. The directive requires all manufacturers of IVDD products sold in Europe to have an "EC Stamp", verifying that they comply with the conditions of the directive. U.S. companies are major exporters of IVDD products to European markets, and thus are directly affected by the directive. One of the major components of this directive is a requirement that products be traceable to "standards of the highest order", e.g., nationally/internationally recognized certified reference materials (CRMs). At present, neither CRMs nor reference methods are available for most of the "A list" analytes that are well-defined chemical species of which there are approximately 80, and "B list" analytes that are less well-defined and number in the hundreds.

Additional SRMs projects being initiated this year include the following :

- **Low Sulfur in Gasoline** (to support proposed US regulation of sulfur content in gasoline for EPA Tier 2 Clean Air Act Amendments)
- **Low Nitric Oxide Standards** (to support measurements needed for development of very low emission vehicles and future automobile emissions regulations)
- **Anion Solutions** {nitrate, bromate, chlorate, chlorite, and cyanide}

- **Gravimetric Elemental Primary Standards** (“Mole standards for metals”)
- **Very Volatile Organic Compounds in Methanol**
- **Organics in Household Dust** (for toxic organic contaminants such as pesticides and PAHs)
- **Fluorescein Fluorescence Intensity** (for calibration of instrumentation widely used by clinical and biotechnology communities)
- **Trans Fatty Acids in Foods** (to support proposed trans fatty acid measurements/nutritional labeling for foods)
- **Anode Tin** (to certify lead and material purity in this important steel coating material manufactured, used, and recycled worldwide; lead content of the recycled high-value tin is of particular importance for food safety, product liability, and environmental concerns)
- **Gunpowder Composition** (to validate forensic methods used to identify gunpowder residues)

Approximately 25 SRM renewals will be completed and efforts will begin for re-certification of an additional 15 or so high priority materials. For the longer term future, we plan to re-institute the NIST program in luminescence standards. The highest priority will be the development of SRMs for fluorescence measurements.

We expect that the NTRM approach will continue to expand as the basis for allowing the commercial sector to provide reference materials to end-users with a well-defined traceability linkage to NIST. Our Optical Filter Standards program will begin in January 2000 with our Elemental Standard Solutions and metal Alloys programs following about a year later. High quality SRMs will continue to be developed to address both national and international measurement problems, but they will be much more expensive and targeted for purchase primarily by other national metrology institutes and commercial producers/distributors. Increasingly, end-user needs will be met via NIST-traceable commercially produced reference materials.

The complex nature of chemical measurements coupled with the increasingly global nature of trade, health, and environmental issues speaks to the need for having the world make measurements using a common “meter stick”. The comprehensive nature of the NIST program in chemical measurements puts us in position to make a very significant contribution to the international chemical measure-

ments community in this regard. In order to do this in both a cost-effective and internationally congenial manner, we are investigating opportunities for partnering with other highly qualified NMIs to provide high quality Certified Reference Materials in specific standards areas. Potential advantages of these proposed partnerships include increased supply, breadth and quality of reference materials for the worldwide chemical measurements community as well as less duplication of effort for more efficient use of limited resources.

The information that has been provided represents a broad range of research and service activities within the general area of chemical measurement science. This overview plus the Selected Technical Activity Reports that follow provide additional details concerning our work and reflect the high quality of our staff. This information also shows how our efforts are impacting U.S. industry's productivity and competitiveness as well as providing measurement infrastructural support for environmental quality and human health assessments.